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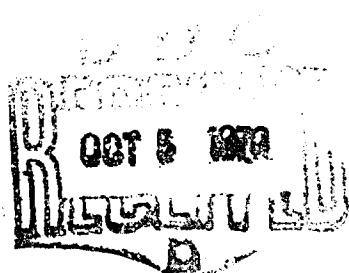
AIR FORCE CAMBRIDGE RESEARCH LABORATORIES

L. G. HANSCOM FIELD, BEDFORD, MASSACHUSETTS

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**Extreme Temperature, Pressure, and Density
Between 30 and 80 km**

ALLEN E. COLE



United States Air Force

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AERONOMY LABORATORY PROJECT 8624

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Abstract

The distributions of temperatures, pressures, and densities derived from rocket observations between 30 and 80 km are examined with special attention given to extremes. Estimates are provided of the medians and values that are exceeded 1 and 10 percent of the time at various latitudes when the monthly means are highest, and of the 99- and 90-percent extremes and medians when monthly means are lowest. The high and low extreme values of temperature, pressure, and density at these levels occur near the pole. Densities are highest in summer when the circulation pattern is dominated by an anticyclone centered over the pole. Lowest values occur in winter and are associated with the polar cyclone that is normally centered off the east coast of northern Greenland.

Meteorological rocket network observations indicate that in tropical areas variability of seasonal means is 1 $\frac{1}{2}$ " than day-to-day variability. In summer, observed day-to-day variations for all latitudes have rms values of 2 to 4 percent for density and 3 to 4°C for temperature at 50 km (typical of the 30- to 60-km layer). These are only slightly greater than random instrumentation errors in meteorological rocket measurements. Near the North Pole in winter the 50-km rms variations of density are nearly 16 percent and the rms variations of temperature are 13 to 14°C. The winter observations at mid and high latitudes show bimodal or rectangular distributions.

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Contents

1. INTRODUCTION	1
2. DATA	2
2.1 Data Available	2
2.2 Data Accuracy	3
3. PROCEDURE	4
4. DISCUSSION	5
5. WORLDWIDE EXTREMES	7
6. SUMMARY AND CONCLUSIONS	7
REFERENCES	31

Illustrations

1. Standard Deviations of the Observed Meteorological Rocket Network (MRN) Densities About Mean Monthly Values as a Function of Latitude	8
2. Frequency Distributions of Temperature Observed Between 30 and 55 Km During the Months With the Highest and Lowest Values	9
3. Density Distributions Shown as Percent Departure From Standard for Months With the Highest and Lowest Mean Monthly Values Between 30 and 50 Km	13

Illustrations

4. Pressure Distributions Shown as Percent Departure From Standard for Months With the Highest and Lowest Mean Monthly Values Between 30 and 50 Km	17
5. Frequency Distributions of Temperatures Observed at Levels Between 50 and 80 Km During Months With the Highest and Lowest Mean Monthly Values	20
6. Density Distributions Shown as Percent Departure From Standard for Levels Between 50 and 80 Km During the Months With the Highest and Lowest Mean Monthly Densities	21
7. Pressure Distributions Shown as Percent Departure From Standard for Levels Between 50 and 80 Km During the Months With the Highest and Lowest Mean Monthly Pressures	22
8. Latitudinal Plots of the Median and Extreme Values of Temperature During the Months With the Highest and Lowest Mean Values	23
9. Latitudinal Plots of the Median and Extreme Values of Density Shown as Percent Departure From Standard for the Months When the Highest and Lowest Values Occur	25
10. Latitudinal Plots of the Median and Extreme Values of Pressure Shown as Percent Departure From Standard for the Months When the Highest and Lowest Values Occur	27

Tables

1. Mean Summer and Winter Densities Based on Two-month (June-July) and Three-month (June-July-August) Periods	29
2. Median and Extreme Temperatures Which Are Exceeded 50, 10, and 1 Percent of the Time During Months With Highest Values, and 50, 90, and 99 Percent of the Time During Months With Lowest Values at the Worst Location in the World (Antarctic Area Excluded)	29
3. Median and Extreme Densities Given as Percent Departure From the U. S. Standard Atmosphere, 1962, Which Are Exceeded 50, 10, and 1 Percent of the Time During Months With Highest Values, and 50, 90, and 99 Percent of the Time During Months With the Lowest Values at the Worst Locations in the World (Antarctic Area Excluded)	30
4. Median and Extreme Pressures Given as Percent Departure From the U. S. Standard Atmosphere, 1962, Which Are Exceeded 50, 10, and 1 Percent of the Time During Months With Highest Values, and 50, 90, and 99 Percent of the Time During Months With the Lowest Values at the Worst Locations in the World (Antarctic Area Excluded)	30

Extreme Temperature, Pressure, and Density Between 30 and 80 km

1. INTRODUCTION

Information on the extreme temperatures, pressures, and densities that are likely to occur at various levels in the stratosphere and mesosphere is frequently needed by engineers for consideration in the design and operation of aerospace vehicles. The limited number and uneven geographical distribution of measurements of atmospheric properties for levels above 30 km make it difficult for meteorologists to provide accurate estimates of such extremes. Models which have been developed to illustrate latitudinal and seasonal variations in atmospheric structure between 30 and 80 km show that the most extreme values occur in polar regions. The highest densities and pressures are observed in summer when the circulation pattern is dominated by an anticyclone centered over the pole; lowest values are associated with a polar cyclone which is normally centered off the eastern coast of northern Greenland in winter (Cole, 1969). Between 30 and 65 km, the warmest temperatures occur over the summer pole, and the coldest over the winter pole. Between 65 and 80 km, the situation is reversed, and temperatures are coldest in summer and warmest in winter.

This paper examines the distributions of observed temperatures, pressures, and densities between 30 and 80 km, and uses an extrapolation technique to obtain

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estimates of the worldwide extremes. Temperatures, pressures, and densities that are exceeded 1, 10, and 50 percent of the time during the months with the highest means and 99, 90, and 50 percent of the time during the months with the lowest means are presented. These data were prepared for use in the revision of MIL-STD-210A, Climatic Extremes for Military Equipment, currently being prepared for publication.

2. DATA

2.1 Data Available

Most of the available data for determining distributions of thermodynamic properties of the atmosphere at levels between 30 and 80 km are from meteorological and experimental rocket soundings in the northern hemisphere. Few observations are available for polar regions where the most extreme values occur, and there is a considerable gap in latitude, from 40 to 60 degrees, where observations are not available.

Routine daily Meteorological Rocket Network (MRN) observations for the years 1965 to 1968 (World Data Center A, 1965-1968) are used to investigate the frequency distributions of temperature, pressure, and density at levels between 30 and 50 km. The measurements considered were taken within a few hours of local noon at the following locations:

Observational Site	Latitude
Ascension	7°59'S
Antigua	17°09'N
Barking Sands	22°02' N
Cape Canaveral	28°27' N
Wallops Island	37°50' N
Churchill	58°44' N
Ft. Greely	64°00'N
Thule	76°33'N

At high- and mid-latitude sites, June and July observations are used to represent one extreme of the annual cycle; December and January observations represent the other extreme. The use of the data for two calendar months, rather than one, greatly increased the sample size and the reliability of the estimates with little effect on extreme values. In the tropics where there is a semi-annual temperature oscillation, distributions are based on the coldest and warmest months. Sample sizes for a given level vary from 35 to 100 observations depending on season and location.

Frequency distributions at levels between 50 and 80 km are based primarily on data derived from sporadic grenade and pitot-static tube experiments performed between 1958 and 1967. Data from experiments at Point Barrow 71°N, Churchill 58°N, and Kronograd 66°N are combined to produce frequency distributions for 65°N; measurements taken at Wallops Island are used to develop distributions for 38°N. The bulk of the winter and summer observations at these levels were taken in February and August. Consequently, three-month rather than two-month seasons are used above 50 km so that February and August observations can be included. The number of summer (June, July, and August) soundings taken at the three sites near 65°N vary from 26 to 29 depending on altitude, and the number of winter soundings (December, January, and February) vary from 27 to 34. Frequency distributions for Wallops Island are based on 12 to 21 observations depending on season and altitude. Only seasonal means could be computed from the sparse data for tropical areas. These means were estimated by fitting an annual curve to data derived from scattered grenade and pitot-static tube experiments conducted at Ascension Island 8°S and Natal 6°S. A small sample of observations taken at Heiss Island 80°N during 1964 and 1965 are also considered in extending the frequency distributions to polar regions.

2.2 Data Accuracy

The equipment used by the Meteorological Rocket Network consists of parachute-borne telemetering sets with thermistors to sense temperature. They are ejected from rockets at altitudes of 60 to 65 km. Errors associated with aerodynamic heating during ascent and ejection and with solar radiation on the bead during descent by parachute have not been completely resolved. The current opinion (Ballard and Rose, 1969) is that little correction is needed at altitudes below 50 km. In any event, the worldwide low-temperature extremes between 30 and 50 km occur near the winter pole, where solar heating of the thermistor is not a problem. However, there is the possibility that, for space at higher altitudes, the temperatures measured during nighttime hours may be several degrees too low due to cooling of the bead by infrared radiation. This is a conservative factor in estimating the frequency of occurrence of low temperatures during the polar night. Direct solar heating of the thermistor during the summer months is also a conservative factor in estimating the frequency of occurrence of extremely warm temperatures.

In addition to possible biases, measurements include random errors. The estimated rms instrumental error in MRN density measurements at 50 km, for example, is 2 to 3 percent (Cole, 1968). This is nearly the same as the observed rms density variability in July (World Data Center A, 1965-1968; Air Weather Service, 1968). See Figure 1. The slightly higher July values for Barking Sands 22°N and

White Sands 32°N, shown in Figure 1, are probably reflections of the diurnal change that is incorporated into the data by the several dozen nighttime measurements that have been taken at these two sites. The lower value at Grand Turk 21°N may be due to a small sample, only 10 observations. The observed standard deviation in January at mid and high latitudes, however, is several times greater than the estimated rms instrumentation error. The random error has little effect on the median values as the errors cancel each other. However, they do increase the magnitude of the observed variability and, as a result, are a conservative factor in estimates of the 1-, 10-, 90-, and 99-percent extremes. The observed rms variation equals the square root of the sum of the squares of the true rms atmospheric variability plus the rms error in measurement. Consequently, the rms measurement error of 2 to 3 percent at 50 km accounts for most of the observed rms variability of 3 percent in summer, but it accounts for only a negligible amount of the 15 to 16 percent rms variability found at high latitudes in winter.

There are insufficient data on which to base statistical studies of the observational errors in temperatures, densities, or pressures derived from grenade and pitot-static tube experiments. The accuracy of the grenade measurements is related to altitude; height increment over which the temperatures are averaged, normally 2.5 to 5.0 km; and the arrangement of microphones on the ground that are used to detect the arrival time of sound waves. Determining the arrival time of the sound waves at the ground is the major source of error. Inaccurate time measurements can result in temperature errors ranging from 1°C at 40 km to 15°C at 90 km (Smith et al, 1964). Since the errors are random they will have little effect on the mean values but will tend to increase the range of extreme values that are observed. It is difficult to assess the magnitude of the effect of these errors on the estimated extremes of temperature, pressure, and density because only a range of possible errors is available from the theoretical studies.

3. PROCEDURE

Temperature, pressure, and density observations for levels between 30 and 80 km for the extreme months at each site are ordered from the smallest to the largest and are plotted on probability paper using the following formula suggested by Kimball (1960).

$$P_i = \frac{(i - 3/8)}{(n + 1/4)}, \quad (1)$$

where i is the order of the observations. Smooth curves are drawn through the points as shown in Figures 2 through 7. The curves are then used as estimates of

the true distributions. When the plotted points appear as a straight line on probability paper, the distribution is normal. If the distributions are bimodal, rectangular, or badly skewed the line of the points is curved. The median and values exceeded 1 and 10 percent of the time when the monthly values are highest, and the median and values exceeded 99 and 90 percent of the time when monthly values are lowest are determined from the individual sets of curves for each location. These data are then plotted on linear graph paper as a function of latitude. See Figures 8 through 10. Smoothed curves extending from pole to equator at levels below 50 km, and from 30° to 90° latitude at levels above 50 km are subjectively fitted to the data points to provide estimates of extreme values at other latitudes.

4. DISCUSSION

Thule is the northernmost station for which adequate MRN data are available for determining the distribution of thermodynamic properties during the summer or warm months, and Ft. Greely 64°N and Churchill 59°N are the northernmost stations for the winter months. The distributions of temperatures during the cold months at Ft. Greely and Churchill, shown in Figures 2C and 2E, are badly skewed; and those for the warm months at Ft. Greely, Churchill, and Thule, shown in Figures 2A, 2B, and 2D, are nearly normal. There is also a slight seasonal variation in the shape of the temperature distribution curves at Wallops Island and Cape Kennedy, shown in Figures 2F to 2I. Similar but less pronounced differences exist between the summer and winter density and pressure distributions shown in Figures 3 and 4 for the same locations.

The summer-to-winter changes in the shape of the distribution curves for Churchill and Ft. Greely reflect a seasonal change in the stability of the upper stratosphere in arctic and subarctic regions. During the winter months stratospheric warmings and coolings produce large day-to-day changes in atmospheric structure. The stratosphere is usually considerably colder or warmer-than-mean seasonal conditions. This produces bimodal distributions of the thermodynamic properties. The magnitude of the winter warmings is illustrated by the 35-km temperature distribution at Churchill during December and January, shown in Figure 2E. Although the median temperature in summer is 28°C warmer than in winter, both the extreme cold and warm temperatures occur in winter. The warm value which is exceeded 1 percent of the time is -5°C in December and January, and -16°C in June and July. In summer the day-to-day variability of temperature, pressure, and density is small and the individual observations are normally distributed about seasonal means at all levels between 30 and 55 km. As

a result, reasonable estimates of the summer frequency distributions can be obtained if the means and standard deviations of a parameter are known.

Figures 5 through 7 show the temperature, density, and pressure distributions between 50 and 80 km for 38°N and 65°N. The distributions of the thermodynamic properties have the same characteristics as those in the upper stratosphere. They are nearly normal in summer and bimodal or rectangular in winter. This suggests that circulation patterns in the mesosphere are related to those in the stratosphere.

Latitudinal plots of the median and extreme values of temperature at levels between 30 and 80 km are shown in Figure 8. During the warm months there is a gradual increase in the median and the 1- and 10-percent values between 30°N and the pole. The medians and the 1-, 10-, 90-, and 99-percent extremes are relatively constant with latitude in tropical and subtropical regions during all periods of the year. In winter the median and the 90- and 99-percent temperatures at levels between 30 and 40 km decrease rapidly from 30°N to the pole. The winter temperatures at levels between 45 and 60 km decrease rapidly from 30°N to 60°N and then remain nearly constant between 60°N and the pole. This is in agreement with a recent study by Cole (1969), who found only small variations in the winter temperature distributions with latitude and longitude between 40 and 55 km in arctic and subarctic regions. At 60 km the cold extremes are nearly the same at all latitudes and at 65 and 70 km the temperatures are coldest at mid and low latitudes. A reversal in the latitudinal temperature gradient occurs near 70 km. Above 70 km temperatures decrease toward the pole in summer and toward the equator in winter, and below 70 km they decrease toward the pole in winter and toward the equator in summer.

Variation in the extreme values of density with latitude are presented in Figure 9. During the warm months density gradually increases with latitude from 30°N to 90°N. The pronounced decrease in density over the same region during winter reflects the strong latitudinal temperature gradients that develop in the troposphere and lower stratosphere. The irregularities in the winter density curves near 60°N are due to the longitudinal variations in atmospheric structure between Churchill 94°W and Ft. Greely 146°W. Although there is considerable difference between the median values for Churchill and Ft. Greely, differences in the 1-percent values are small. The latitudinal and longitudinal pressure variations, shown in Figure 10, are similar to those for density. As expected, the extreme values of pressure and density at mid and high latitudes fall on either side of the U. S. Standard Atmosphere values, represented by the zero departure lines in each figure.

Latitudinal curves of temperature, density, and pressure extremes above 50 km are fitted to values derived from distributions for two sites, 38°N and 65°N latitude,

and mean seasonal values derived from scattered data in tropical areas. As previously mentioned, the frequency distributions at each of the two sites are based on observations taken during a three-month rather than a two-month period. An examination of data derived from grenade and pressure gage experiments at Wallops Island and Churchill indicates that mean seasonal values of density and pressure between 50 and 80 km are greater in summer and less in winter when based on observations taken for a two-month rather than a three-month period. Mean summer and winter temperatures for 55 and 70 km and densities for 60 and 70 km that are based on both two-month and three-month seasons are shown in Table 1. The two-month and three-month mean seasonal temperatures are nearly the same. Winter densities based on a two-month (June and July) average are 4 to 5 percent less than those based on a three-month (June, July, August) period, and summer densities for the two-month season are 4 percent greater at Churchill and 1 percent greater at Wallops Island.

5. WORLDWIDE EXTREMES

Extreme temperatures, pressures, and densities at various levels between 30 and 80 km that have a 1-, 10-, 50-, 90-, and 99-percent probability of being exceeded during the worst season (two-month period) and at the worst location are presented in Tables 2, 3, and 4.

The values of pressure and density above 50 km have been adjusted to reflect the extremes that would occur during the most extreme two-month periods, rather than during a three-month period. The density and pressure were adjusted by increasing all points on the frequency distributions by 4 percent in summer and decreasing them by 5 percent in winter. These estimated worldwide extremes (antarctic excluded) are based on extrapolated data for 85°N, and are more extreme than conditions observed at any of the observational sites. The only exceptions are temperatures for levels between 60 and 70 km. The fragmentary data available at these altitudes indicate that minimum and maximum temperatures occur at mid or low latitudes. Confidence in the estimates decreases rapidly above 50 km.

6. SUMMARY AND CONCLUSIONS

Worldwide extremes (antarctic area excluded) of temperature, pressure, and density given in Tables 2 to 4 for altitudes between 30 and 80 km are considered to be conservative estimates, as they are based on observations which include random instrumentation errors. Greater confidence can be placed in the values for levels

below 50 km, where the sample sizes are larger and the magnitude of the random instrumentation errors has been evaluated.

Observations of temperatures, pressures and densities for levels between 30 and 80 km approach a normal distribution in summer. In winter all three parameters tend to have bimodal or rectangular distribution at high and mid altitudes.

The magnitude of the observed day-to-day variations in the MRN density observations near 50 km during the summer months at all latitudes and year-round in the tropics is approximately the same as estimated random instrumentation errors in the measurements.

Seasonal and latitudinal variability of median and extreme values of temperature, pressure, and density is smallest in tropical and subtropical areas and largest in the polar region.

Since both high and low worldwide extremes are found near the poles, additional rocket observations are needed in these regions for more refined estimates of extremes between 30 and 80 km.

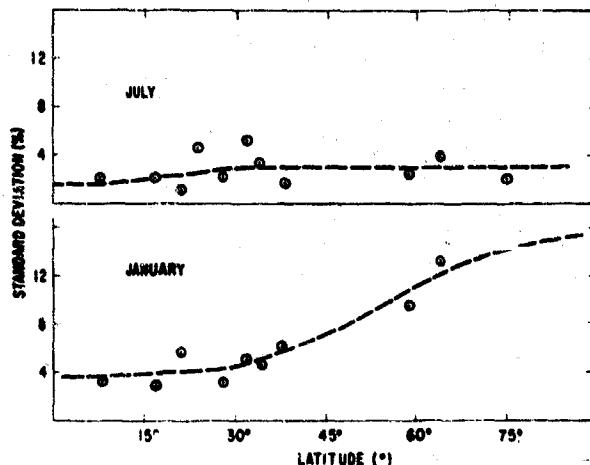


Figure 1. Standard Deviations of the Observed Meteorological Rocket Network (MRN) Densities About Mean Monthly Values as a Function of Latitude

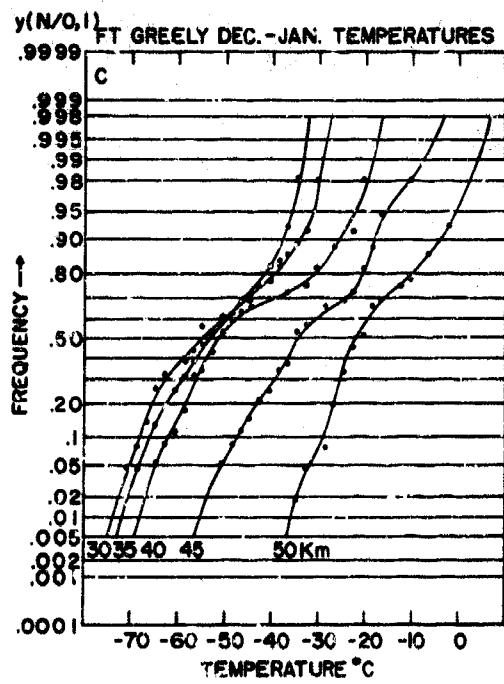
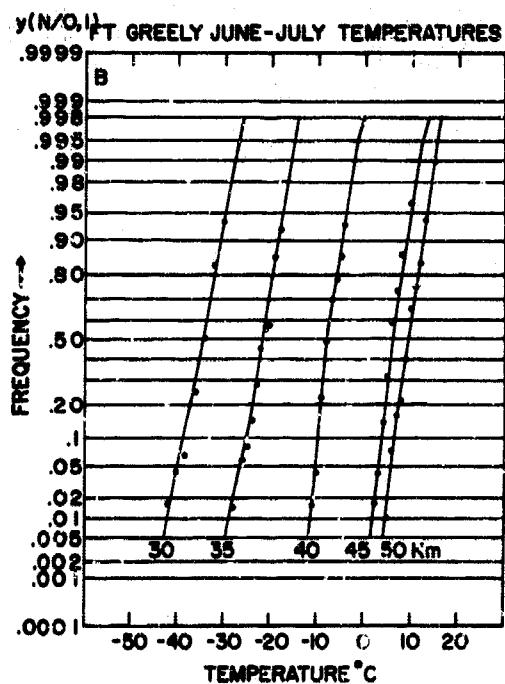
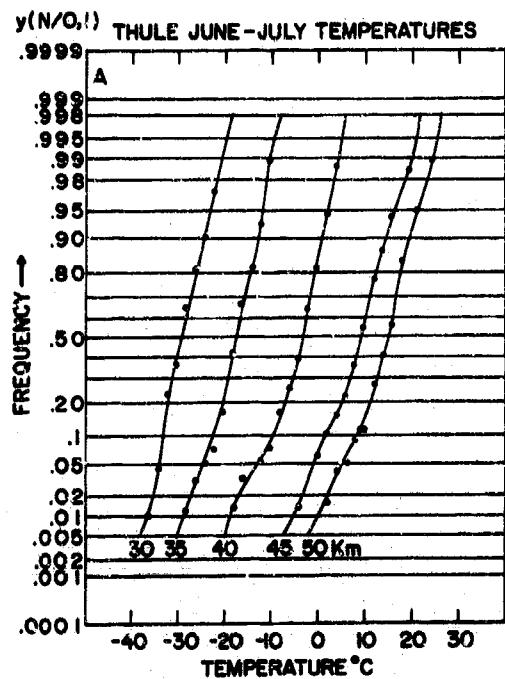


Figure 2. Frequency Distributions of Temperature Observed Between 30 and 55 Km During the Months With the Highest and Lowest Values (Sheet 1 of 4)

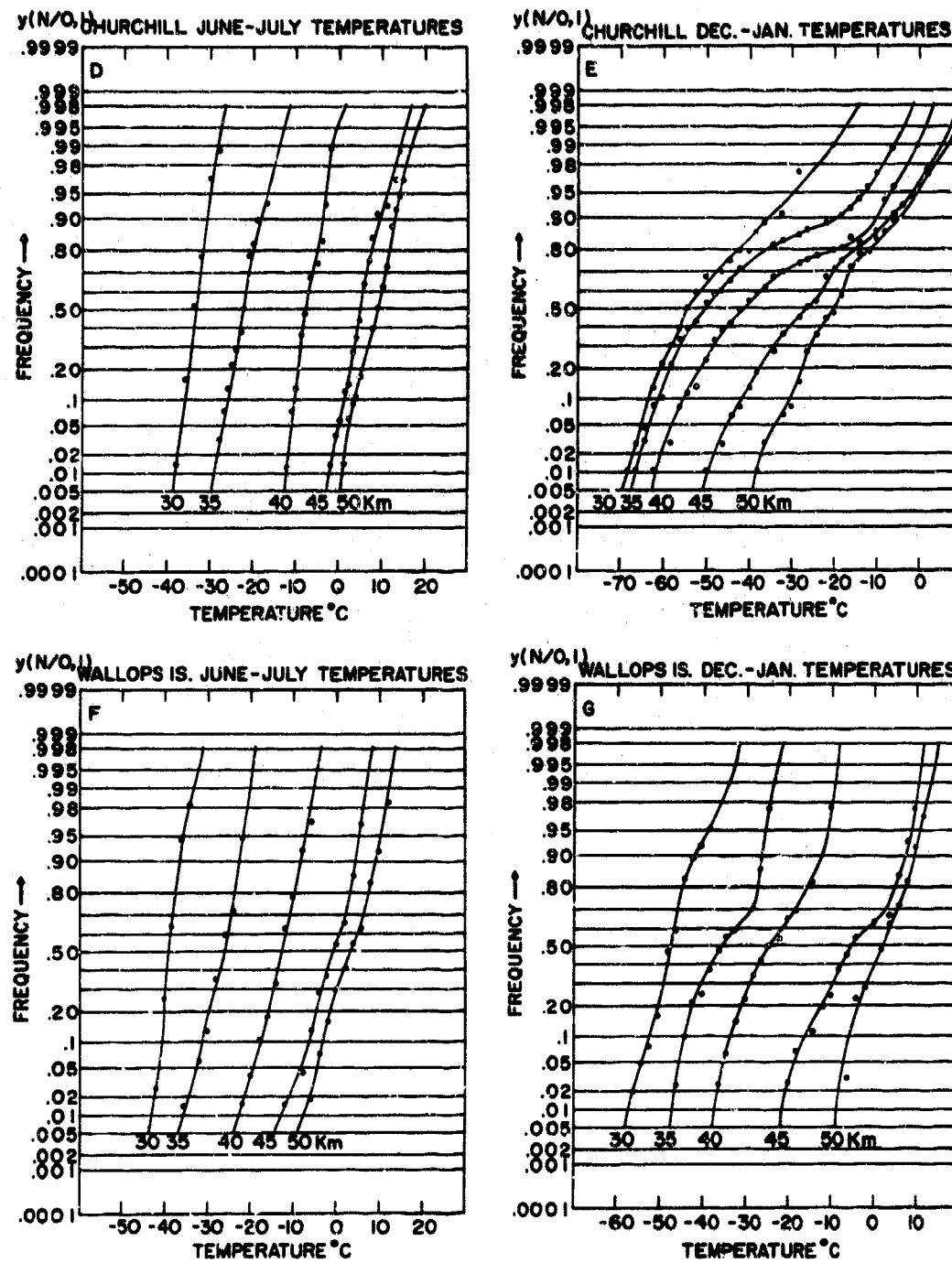


Figure 2. Frequency Distributions of Temperature Observed between 30 and 55 Km During the Months With the Highest and Lowest Values (Sheet 2 of 4)

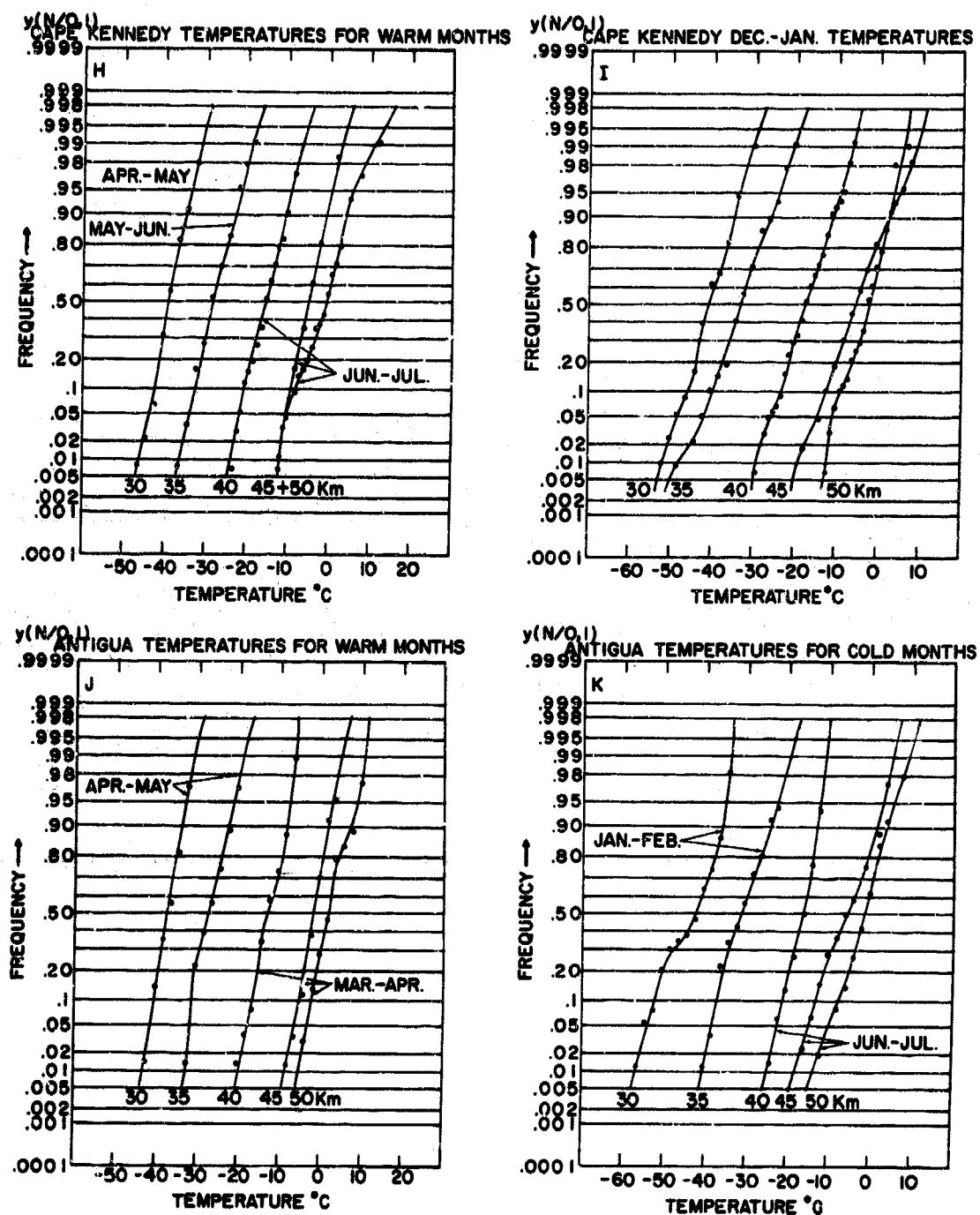


Figure 2. Frequency Distributions of Temperature Observed Between 30 and 55 Km During the Months With the Highest and Lowest Values (Sheet 3 of 4)

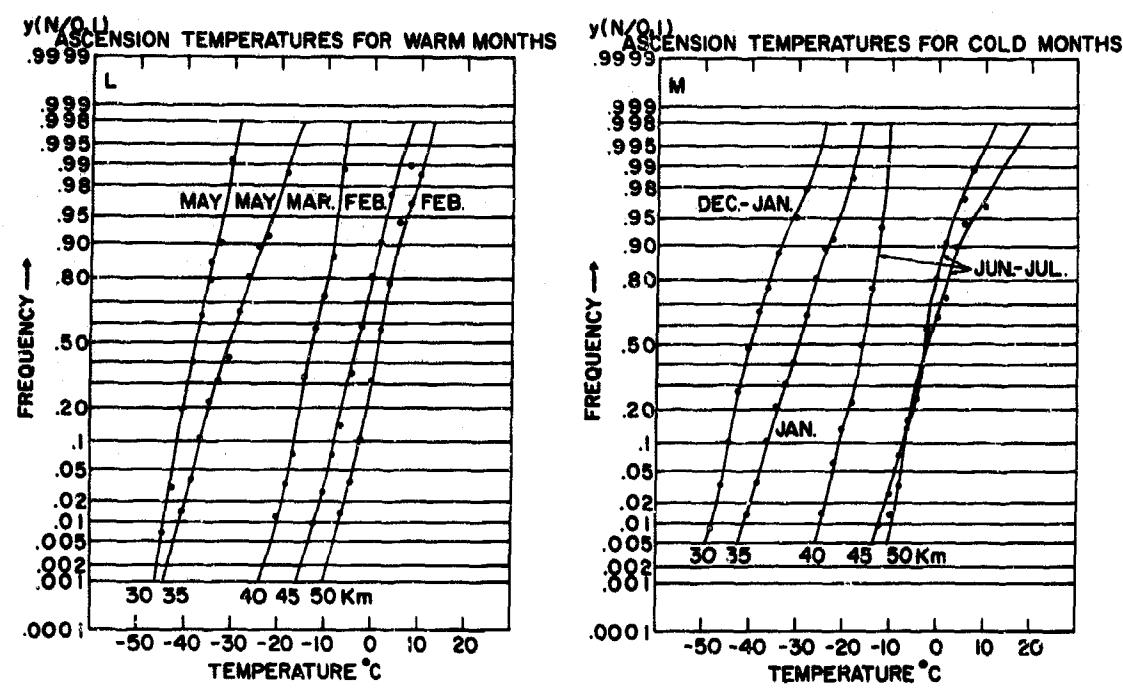


Figure 2. Frequency Distributions of Temperature Observed Between 30 and 55 Km During the Months With the Highest and Lowest Values (Sheet 4 of 4)

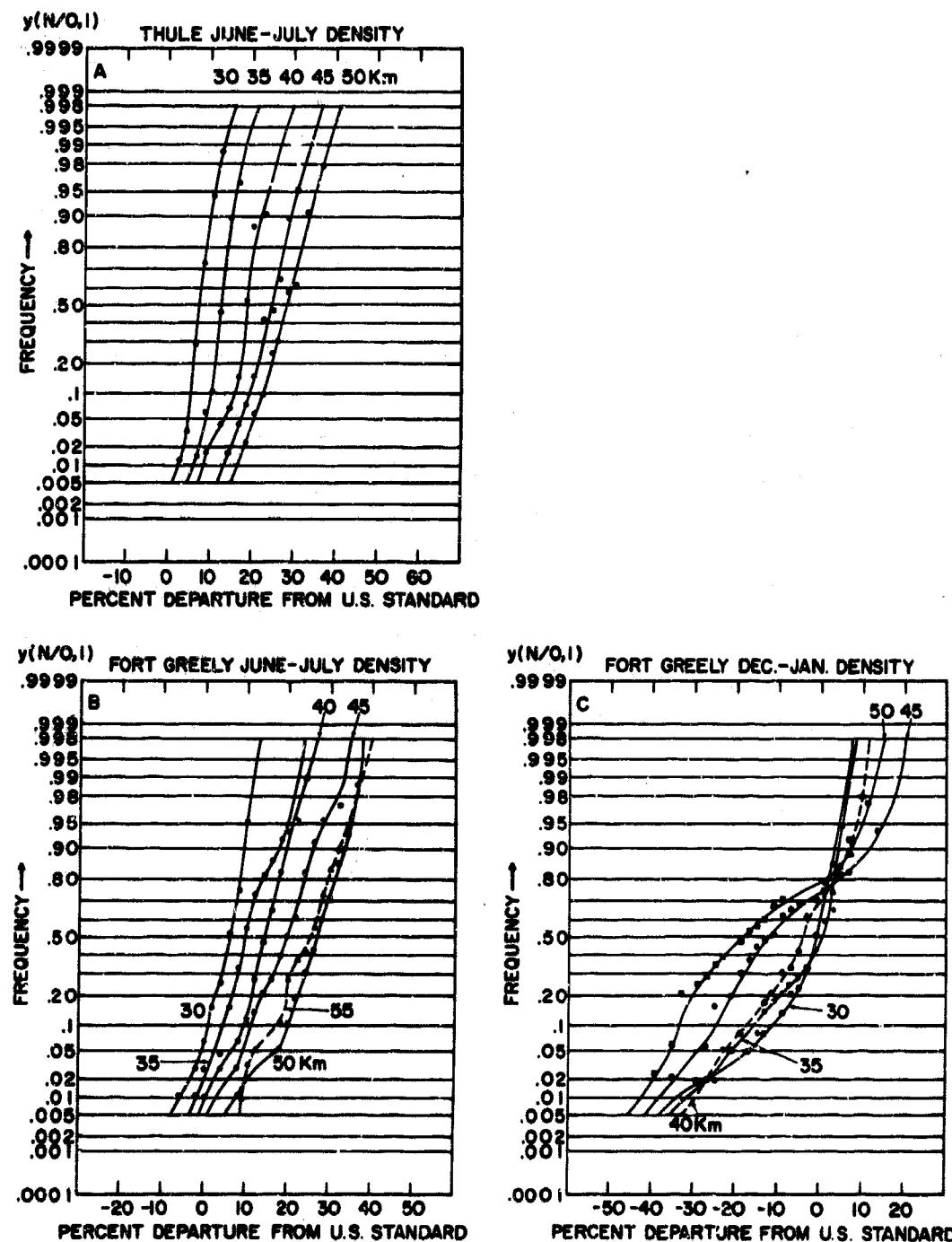


Figure 3. Density Distributions Shown as Percent Departure From Standard for Months With the Highest and Lowest Mean Monthly Values Between 30 and 50 Km (Sheet 1 of 4)

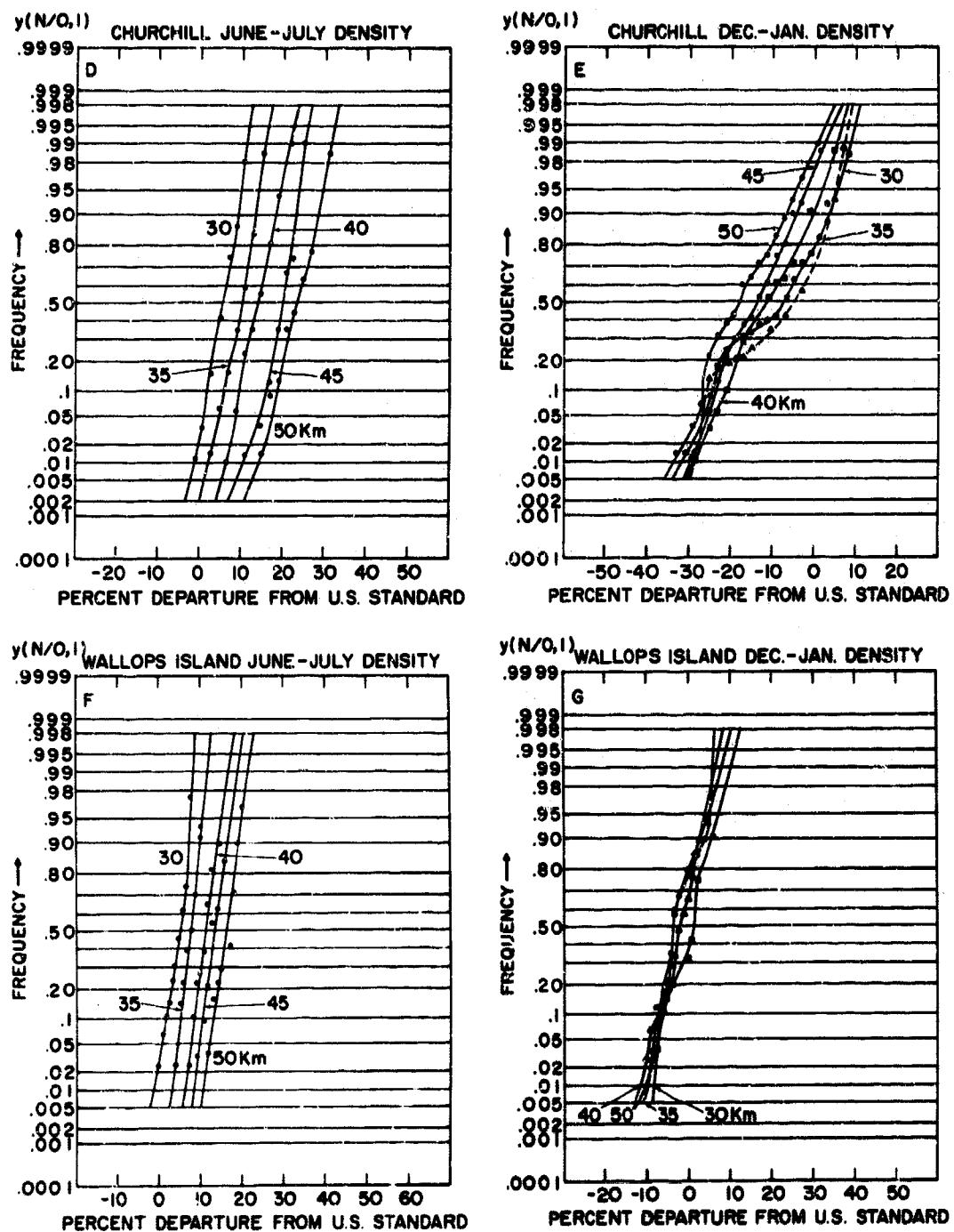


Figure 3. Density Distributions Shown as Percent Departure From Standard for Months With the Highest and Lowest Mean Monthly Values Between 30 and 50 Km (Sheet 2 of 4)

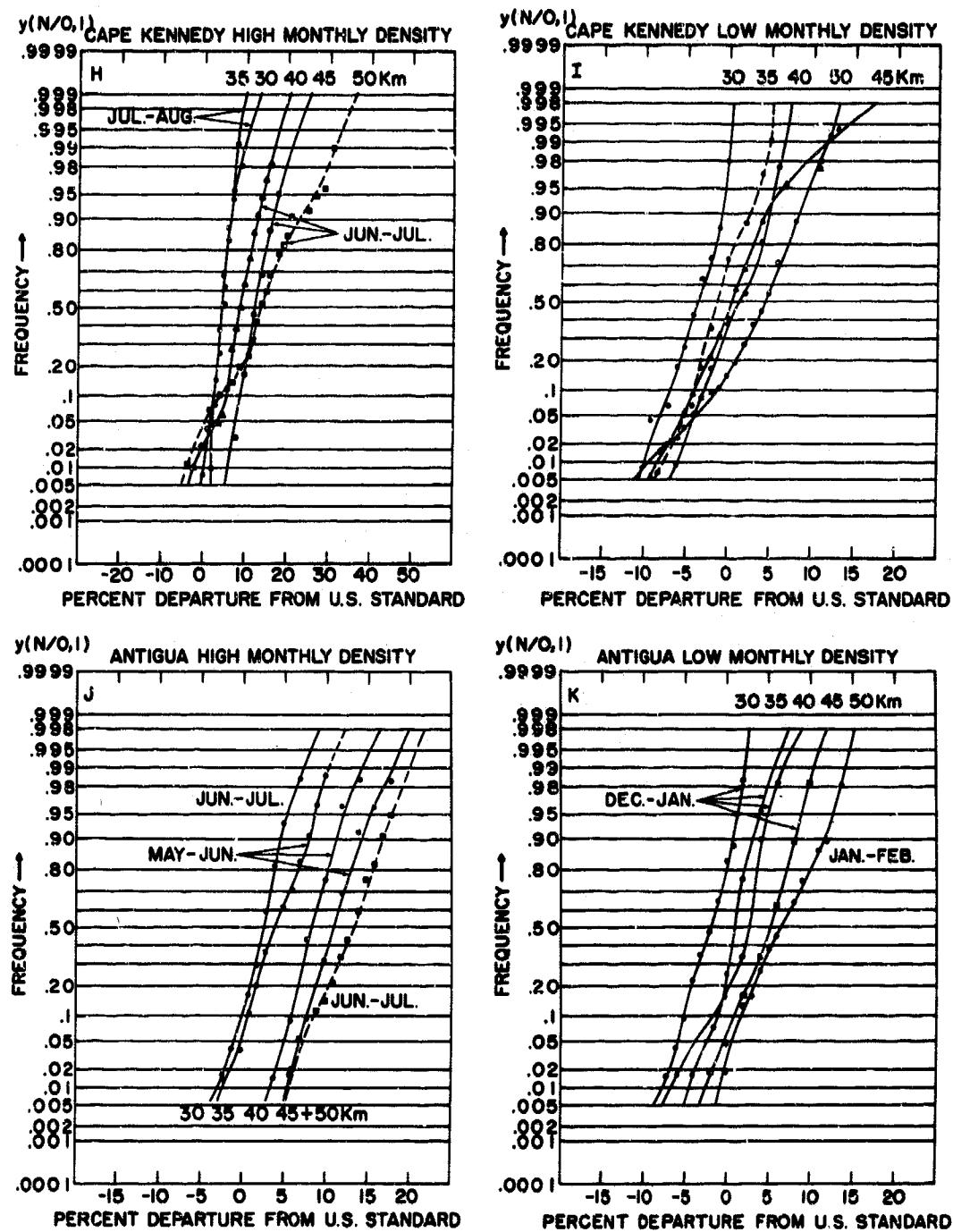


Figure 3. Density Distributions Shown as Percent Departure From Standard for Months With the Highest and Lowest Mean Monthly Values Between 30 and 50 Km (Sheet 3 of 4)

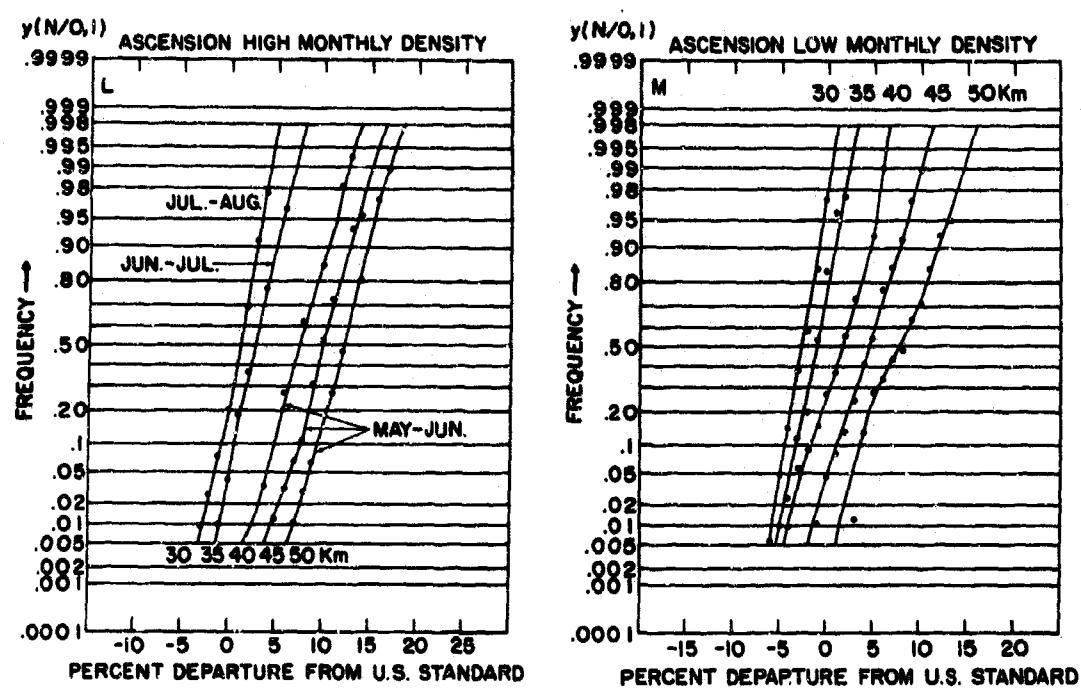


Figure 3. Density Distributions Shown as Percent Departure From Standard for Months With the Highest and Lowest Mean Monthly Values Between 30 and 50 Km
(Sheet 4 of 4)

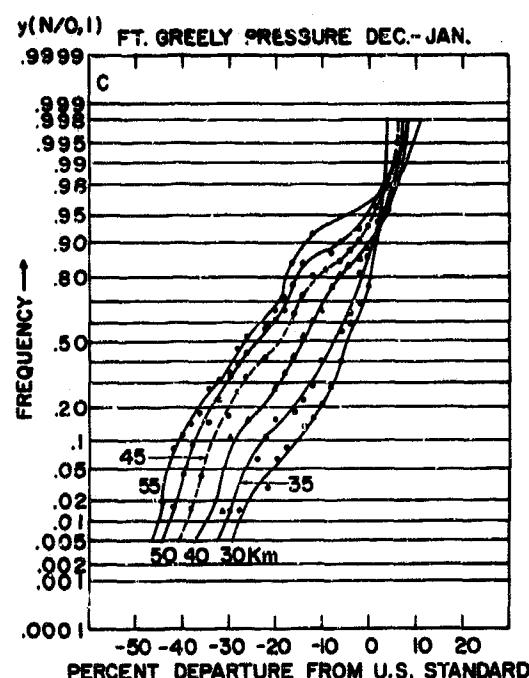
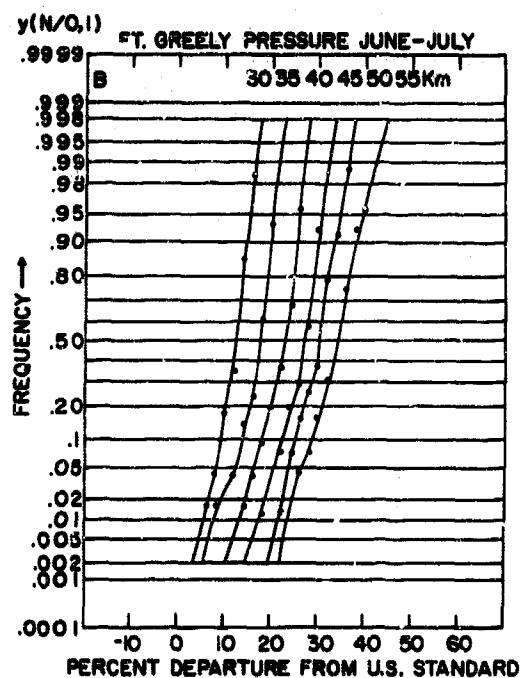
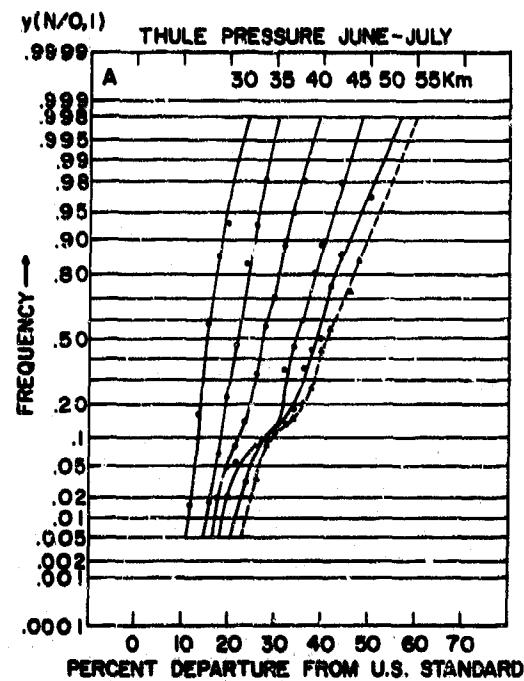


Figure 4. Pressure Distributions Shown as Percent Departure From Standard for Months With the Highest and Lowest Mean Monthly Values Between 30 and 50 Km (Sheet 1 of 3)

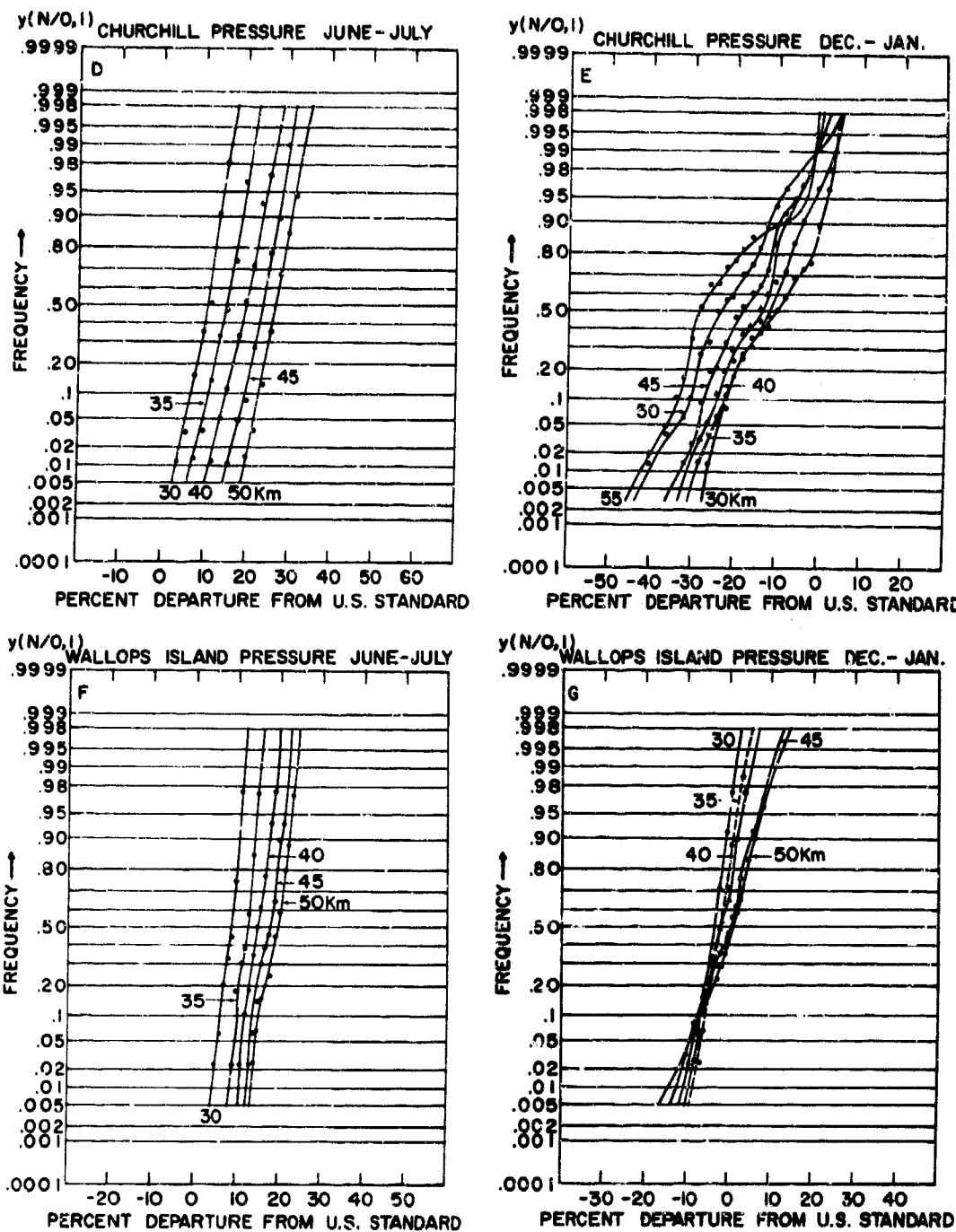


Figure 4. Pressure Distributions Shown as Percent Departure From Standard for Months With the Highest and Lowest Mean Monthly Values Between 30 and 50 Km
(Sheet 2 of 3)

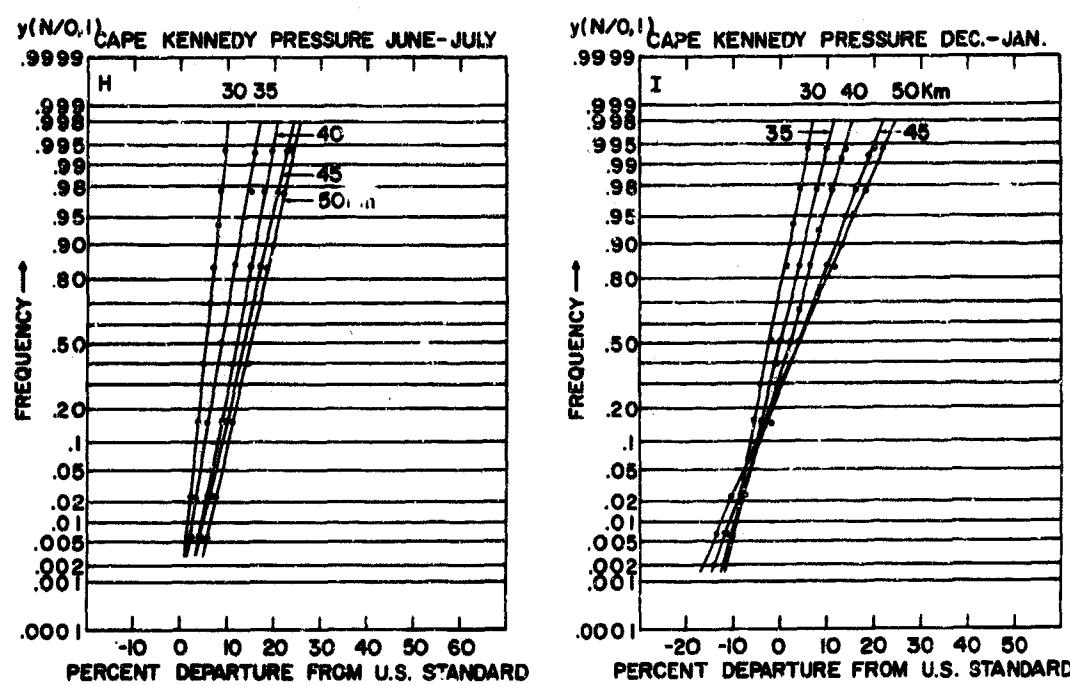


Figure 4. Pressure Distributions Shown as Percent Departure From Standard for Months With the Highest and Lowest Mean Monthly Values Between 30 and 50 Km
(Sheet 3 of 3)

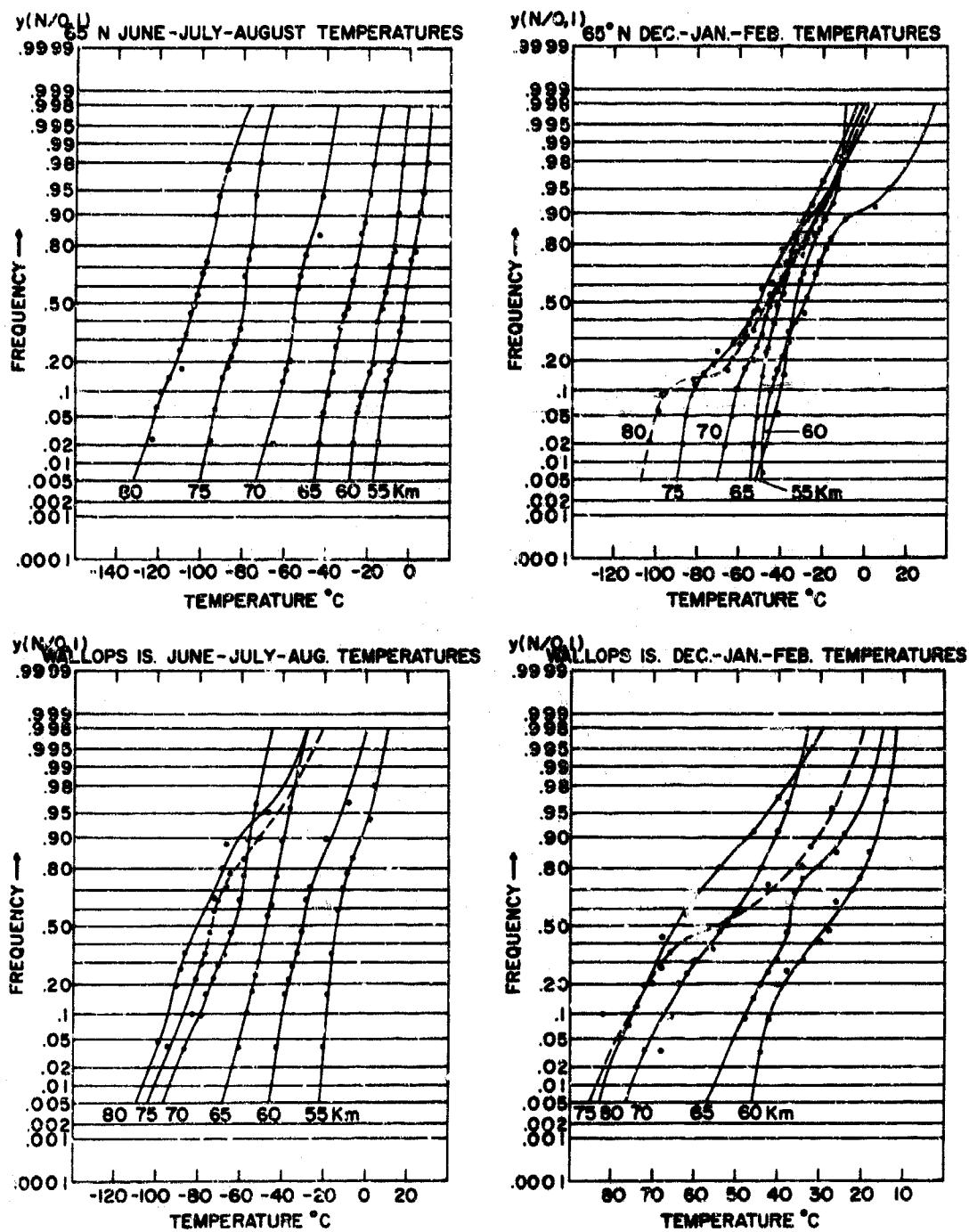


Figure 5. Frequency Distributions of Temperatures Observed at Levels Between 50 and 80 Km During Months With the Highest and Lowest Mean Monthly Values. Values for 65°N are based on observations taken at Churchill 58°N, Point Barrow 71°N, and Kronograd 66°N

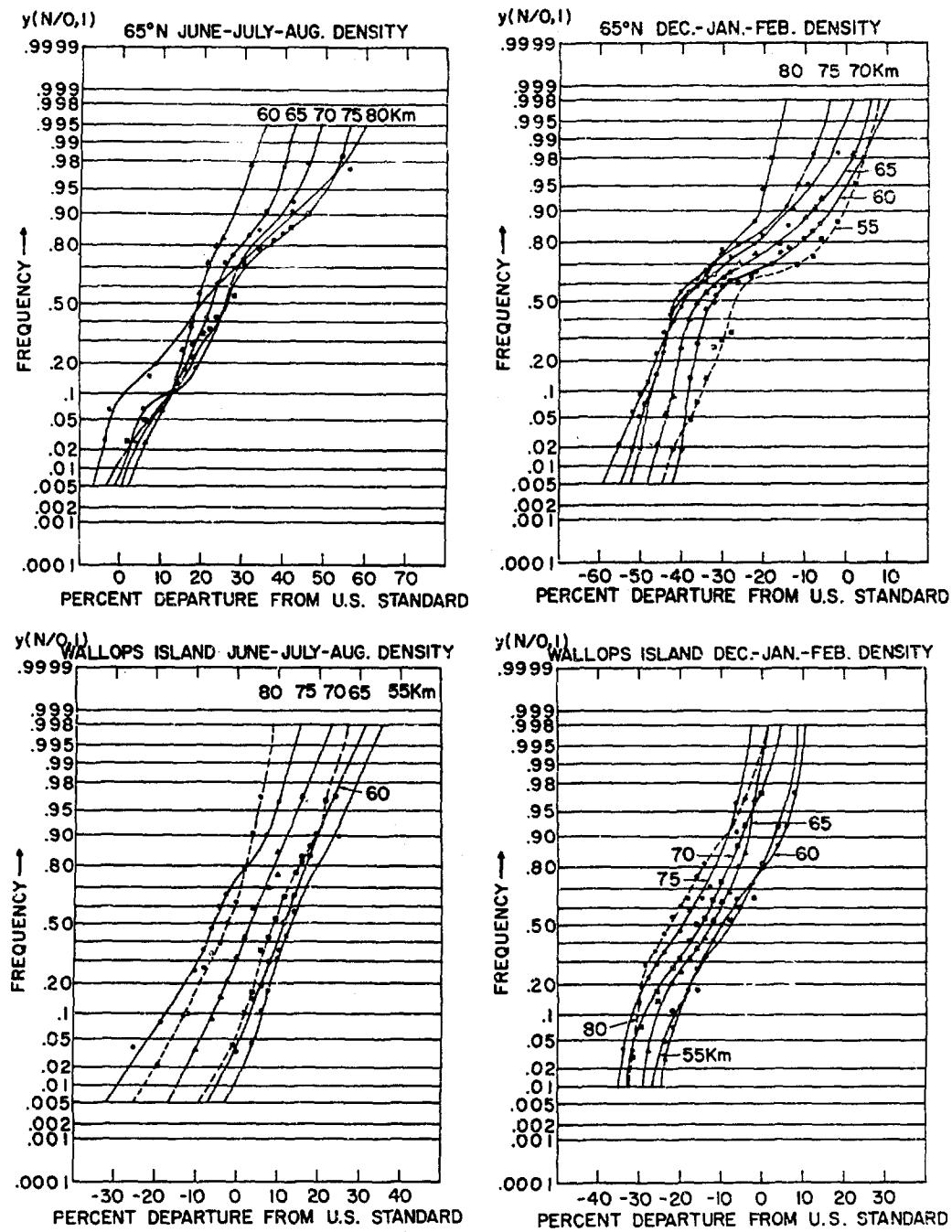


Figure 6. Density Distributions Shown as Percent Departure From Standard for Levels Between 50 and 80 Km During the Months With the Highest and Lowest Mean Monthly Densities. Values for 65°N are based on observations at Churchill 59°N, Point Barrow 71°N, and Kronograd 66°N

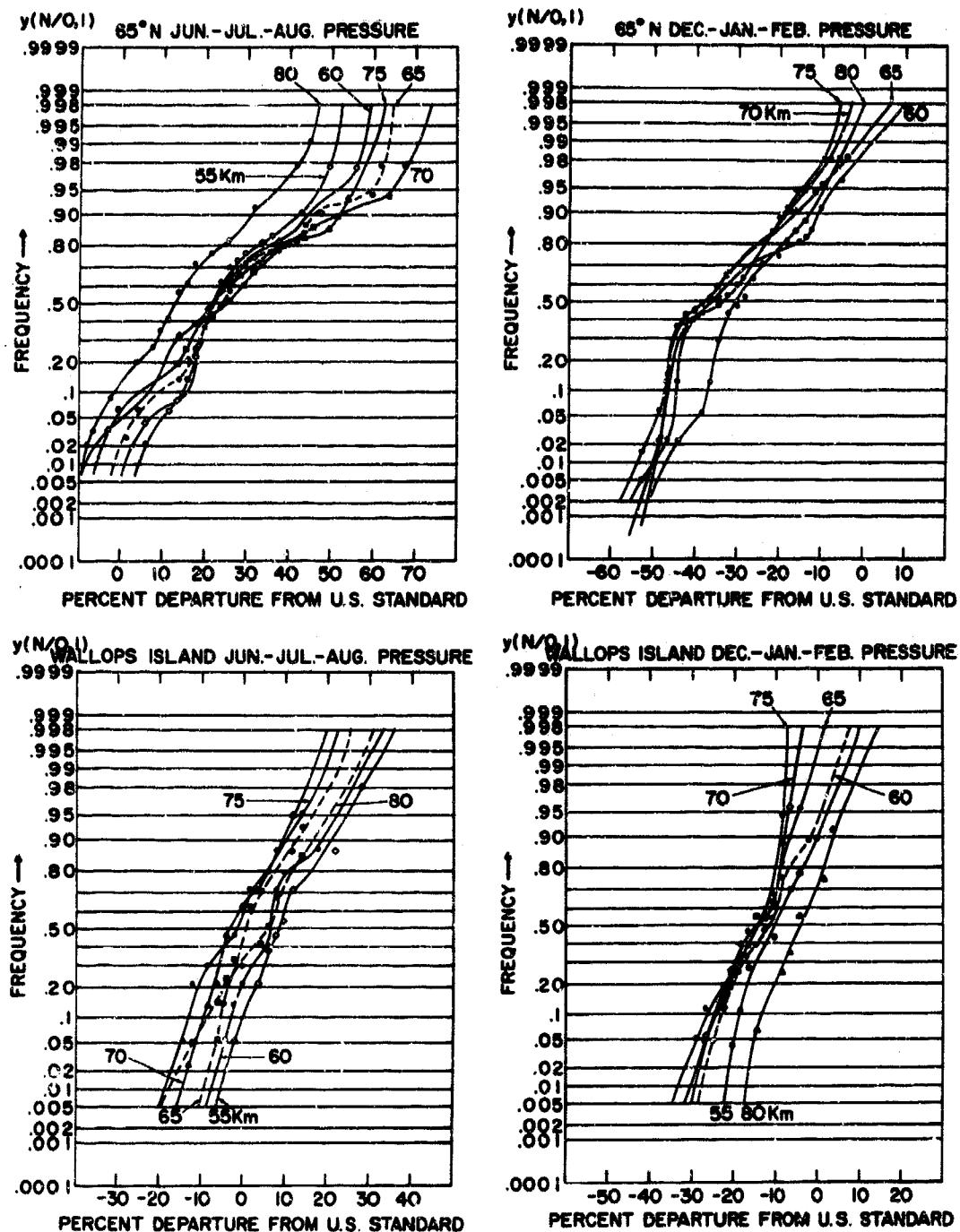


Figure 7. Pressure Distributions Shown as Percent Departure From Standard for Levels Between 50 and 80 Km During the Months With the Highest and Lowest Mean Monthly Pressures. Values for 85°N are based on observations at Churchill 59°N and Point Barrow 71°N

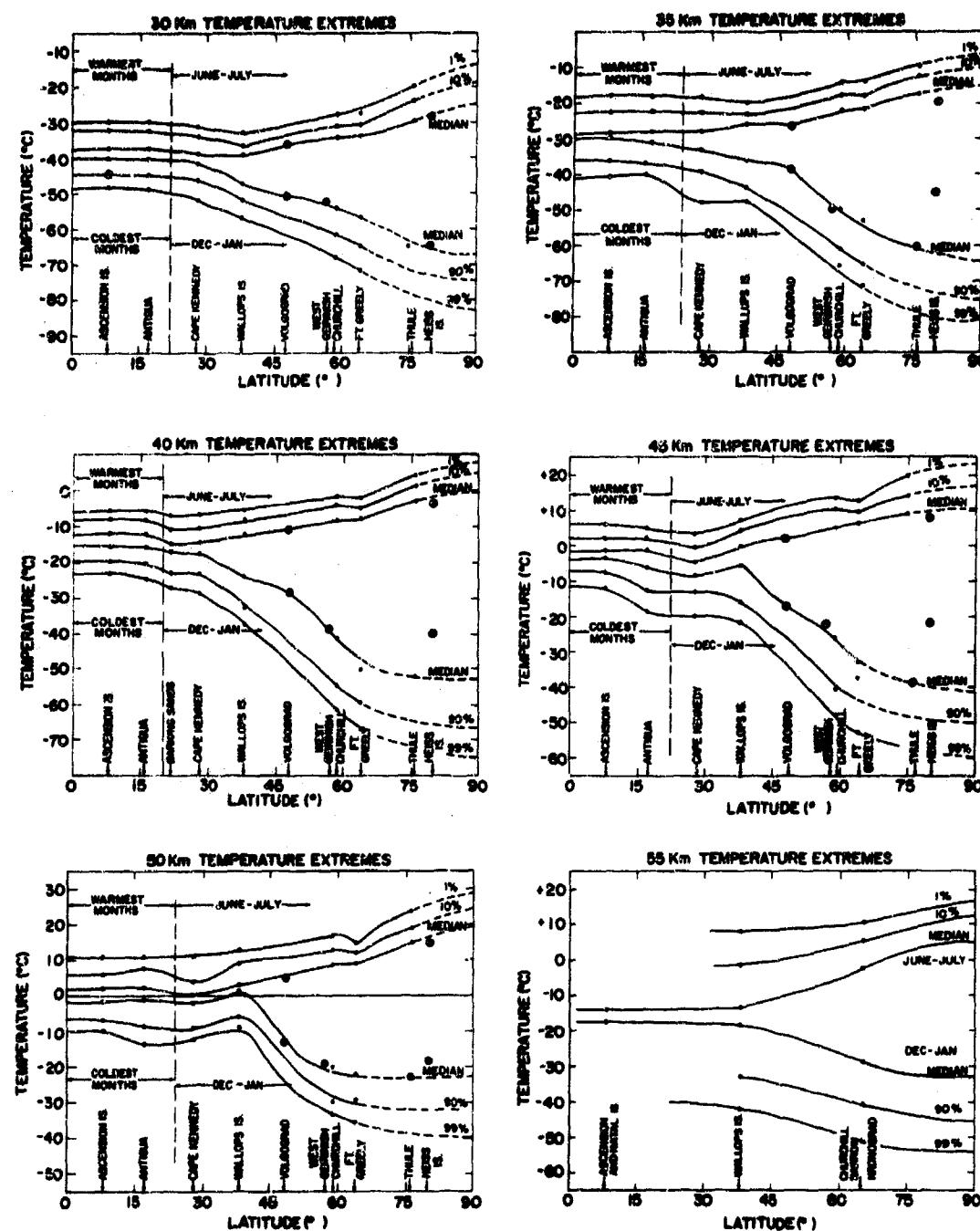


Figure 8. Latitudinal Plots of the Median and Extreme Values of Temperature During the Months With the Highest and Lowest Mean Values (Sheet 1 of 2)

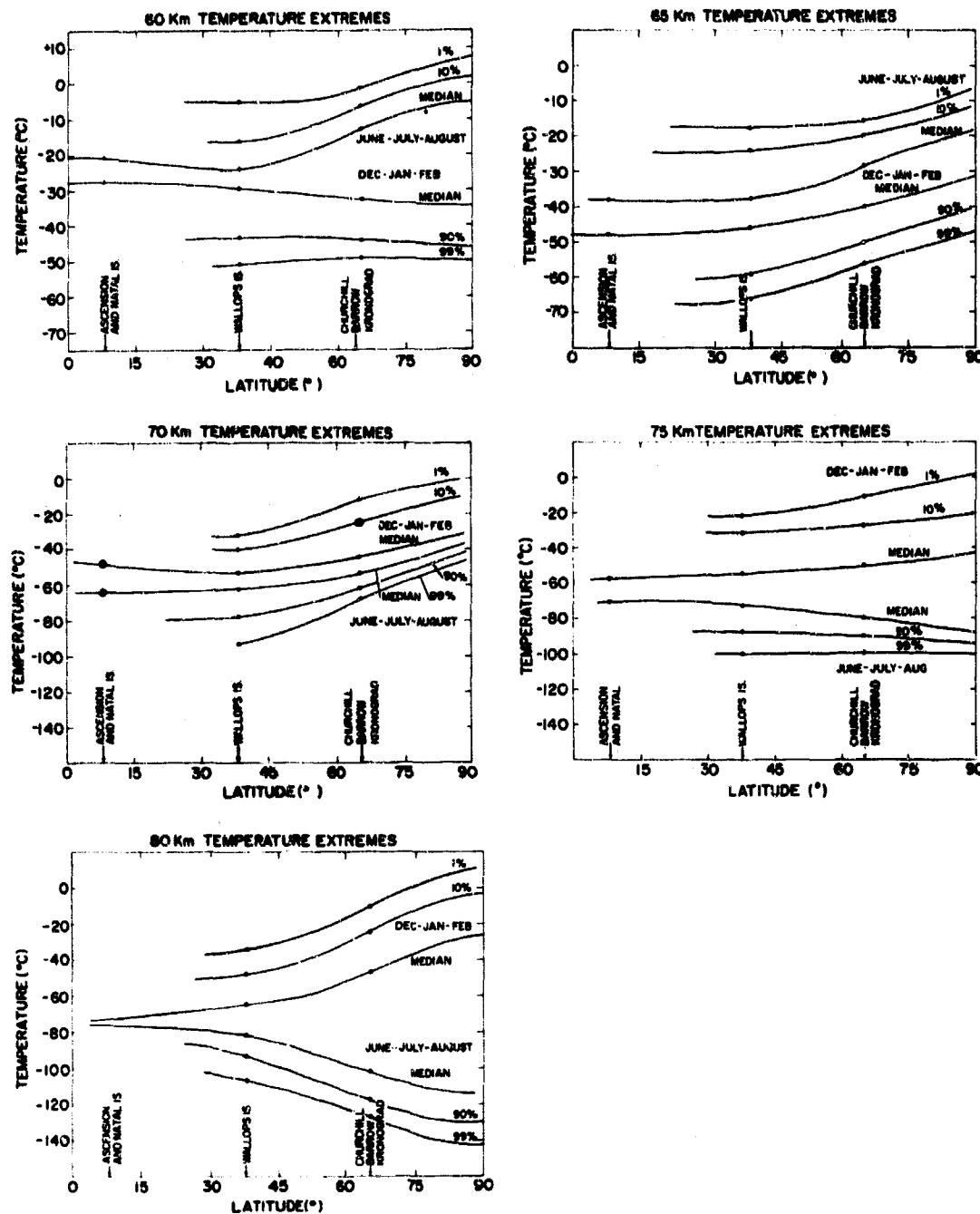


Figure 8. Latitudinal Plots of the Median and Extreme Values of Temperature During the Months With the Highest and Lowest Mean Values (Sheet 2 of 2)

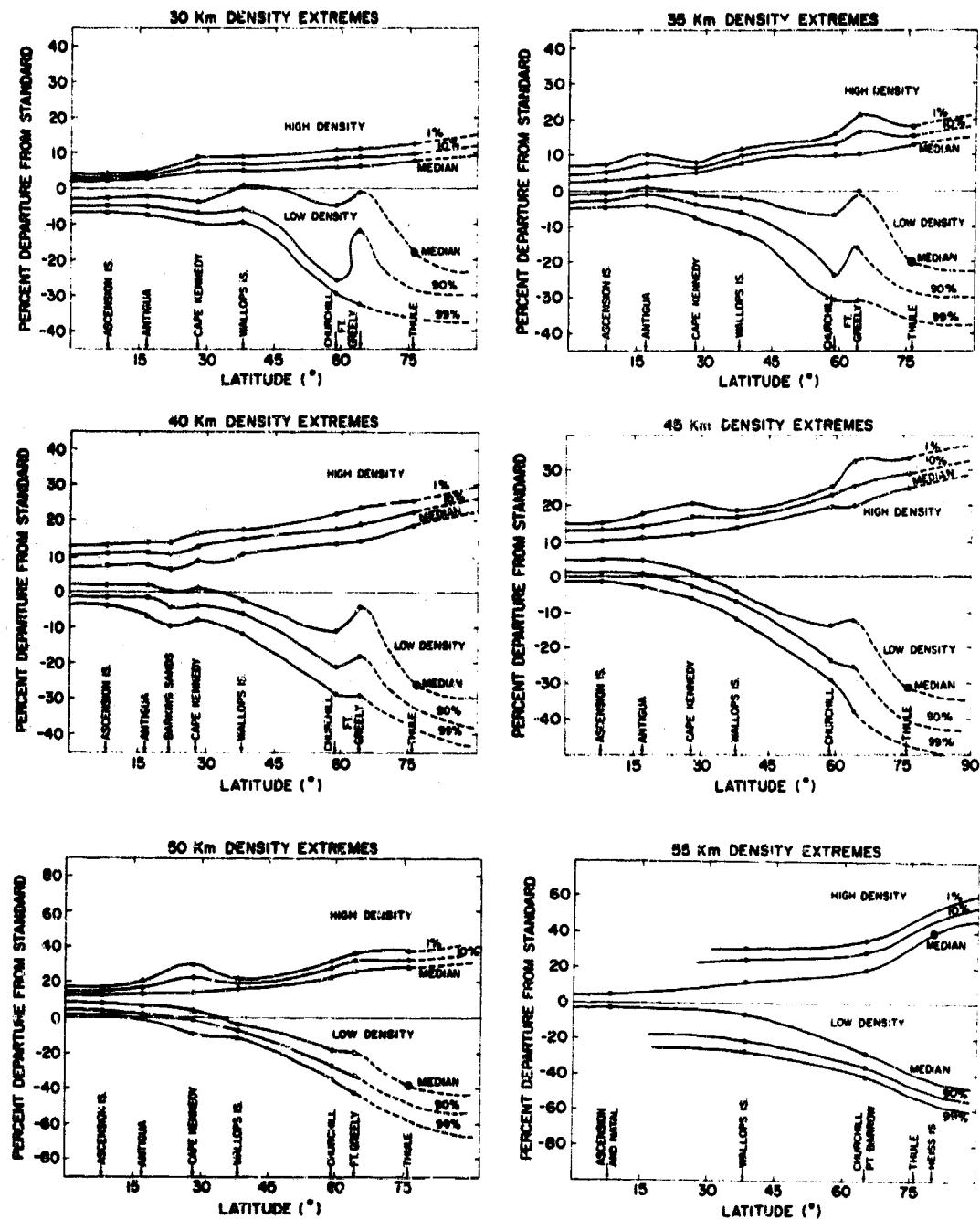


Figure 9. Latitudinal Plots of the Median and Extreme Values of Density Shown as Percent Departure From Standard for the Months When the Highest and Lowest Values Occur (Sheet 1 of 2)

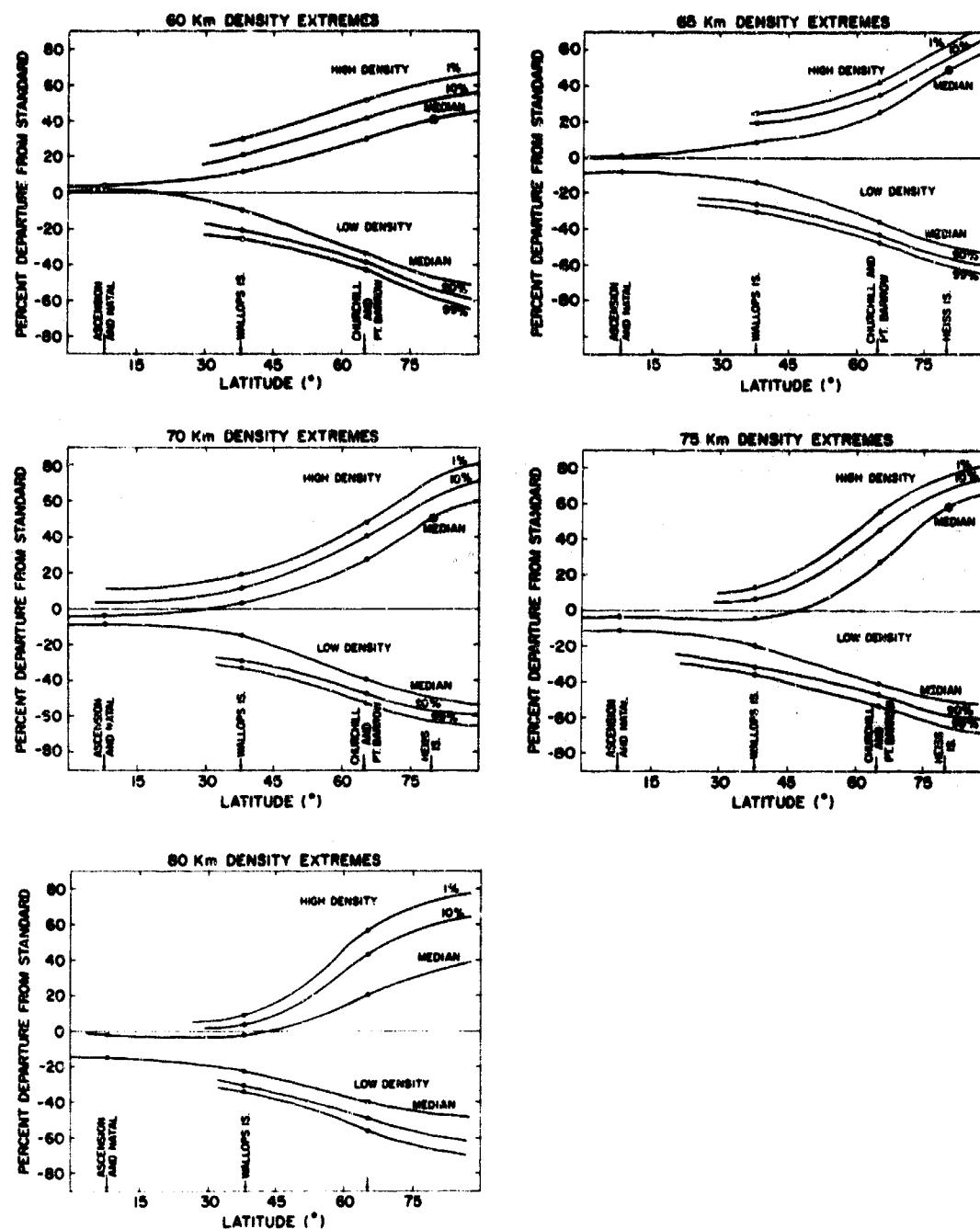


Figure 9. Latitudinal Plots of the Median and Extreme Values of Density Shown as Percent Departure From Standard for the Months When the Highest and Lowest Values Occur (Sheet 2 of 2)

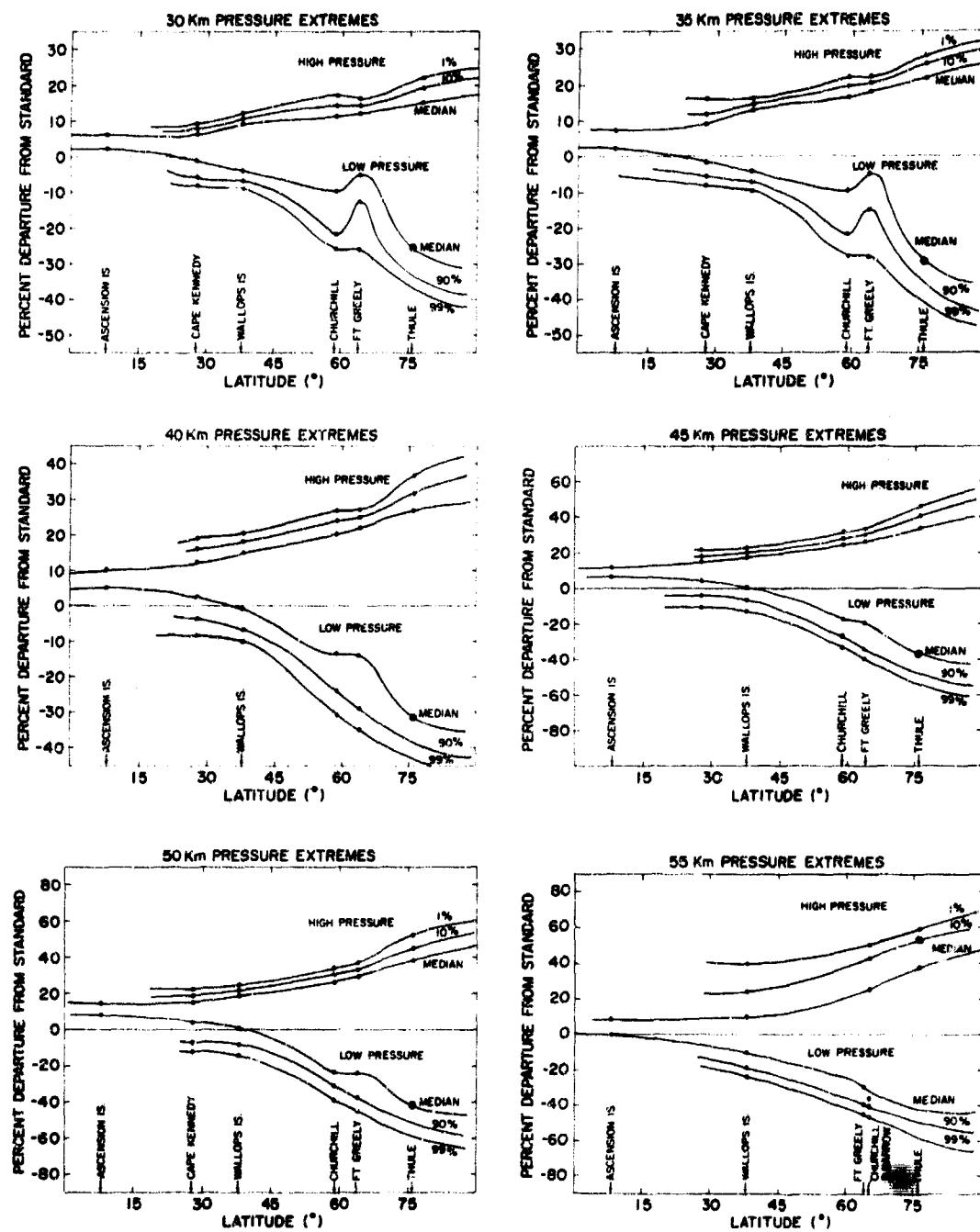


Figure 10. Latitudinal Plots of the Median and Extreme Values of Pressure Shown as Percent Departure From Standard for the Months When the Highest and Lowest Values Occur (Sheet 1 of 2)

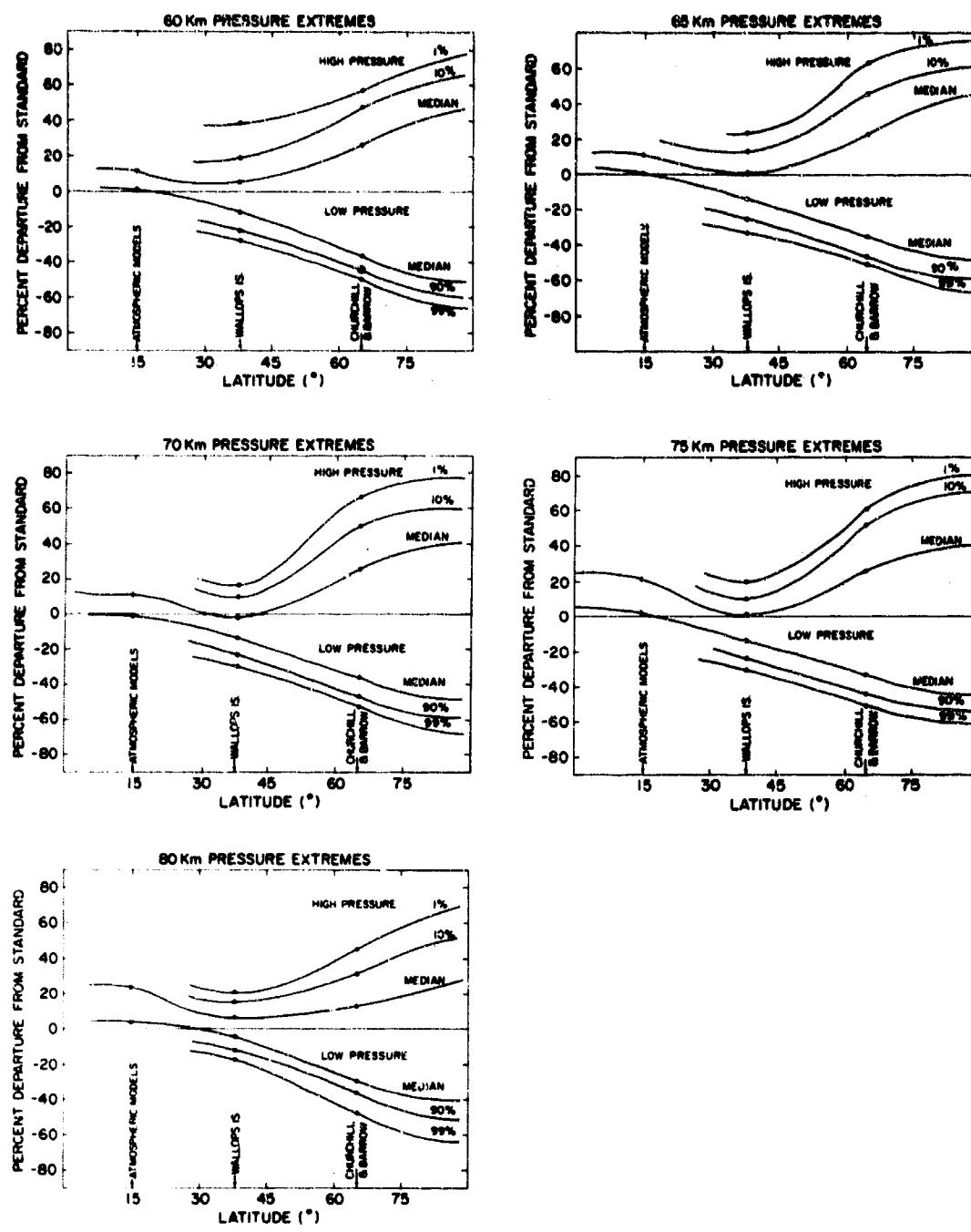


Figure 10. Latitudinal Plots of the Median and Extreme Values of Pressure Shown as Percent Departure From Standard for the Months When the Highest and Lowest Values Occur (Sheet 2 of 2)

Table 1. Mean Summer and Winter Densities Based on Two-month (June-July) and Three-month (June-July-August) Periods

Location	Parameter	Winter		Summer	
		3-Month	2-Month	3-Month	2-Month
Churchill	(55 km Temp.)	253	253	270	271
Wallops	(55 km Temp.)	253	252	267	264
Churchill	(70 km Temp.)	240	243	216	217
Wallops	(70 km Temp.)	221	222	207	207
Churchill	(60 km Density)	-33%	-38%	+21%	+23%
Wallops	(60 km Density)	-15%	-20%	+13%	+13%
Churchill	(70 km Density)	-41%	-45%	+25%	+29%
Wallops	(70 km Density)	-20%	-24%	+ 6%	+ 7%

Table 2. Median and Extreme Temperatures Which Are Exceeded 50, 10, and 1 Percent of the Time During Months With Highest Values, and 50, 90, and 99 Percent of the Time During Months With Lowest Values at the Worst Location in the World (Antarctic Area Excluded)

Altitude (km)	Low Temperatures			High Temperatures		
	Median	90%	99%	Median	10%	1%
30	- 67	- 74	- 82	-24	-20	-15
35	- 64	- 75	- 81	-16	-11	- 7
40	- 52	- 66	- 74	- 1	+ 4	+ 8
45	- 42	- 50	- 59	+10	+17	+22
50	- 23	- 32	- 40	+18	+23	+28
55	- 33	- 45	- 54	+ 5	+12	+16
60	- 35	- 45	- 56	- 5	+ 2	+ 6
65	- 38	- 60	- 66	-20	-12	- 8
70	- 62	- 79	- 93	-33	-12	- 2
75	- 87	- 93	-100	-45	-22	0
80	-112	-130	-142	-27	- 5	+10

Table 3. Median and Extreme Densities Given as Percent Departure From the U. S. Standard Atmosphere, 1962, Which Are Exceeded 50, 10, and 1 Percent of the Time During Months With Highest Values, and 50, 90, and 99 Percent of the Time During Months With the Lowest Values at the Worst Locations in the World (Antarctic Area Excluded)

Altitude (km)	Lowest Densities			Highest Densities		
	Median	90%	99%	Median	10%	1%
30	-23	-30	-37	9	11	14
35	-23	-30	-37	15	17	21
40	-29	-37	-42	22	25	28
45	-34	-43	-50	28	32	36
50	-42	-52	-65	32	35	42
55	-51	-58	-63	47	54	61
60	-54	-61	-67	47	58	68
65	-57	-62	-69	58	66	73
70	-57	-62	-69	60	71	80
75	-57	-62	-72	66	76	83
80	-53	-65	-74	41	65	79

Table 4. Median and Extreme Pressures Given as Percent Departure From the U. S. Standard Atmosphere, 1962, Which Are Exceeded 50, 10, and 1 Percent of the Time During Months With Highest Values, and 50, 90, and 99 Percent of the Time During Months With the Lowest Values at the Worst Locations in the World (Antarctic Area Excluded)

Altitude (km)	Lowest Pressures			Highest Pressures		
	Median	90%	99%	Median	10%	1%
30	-31	-38	42	+16	+21	+24
35	-35	-42	-47	+25	+29	+32
40	-35	-42	-48	+29	+36	+41
45	-42	-54	-60	+38	+47	+54
50	-46	-58	-64	+43	+52	+59
55	-49	-57	-64	+47	+61	+70
60	-55	-64	-71	+48	+67	+78
65	-53	-63	-70	+48	+63	+77
70	-53	-63	-72	+42	+63	+79
75	-49	-58	-65	+42	+63	+81
80	-45	-55	-67	+28	+53	+71

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13. ABSTRACT

The distributions of temperatures, pressures, and densities derived from rocket observations between 30 and 80 km are examined with special attention given to extremes. Estimates are provided of the medians and values that are exceeded 1 and 10 percent of the time at various latitudes when the monthly means are highest, and of the 99- and 90-percent extremes and medians when monthly means are lowest. The high and low extreme values of temperature, pressure, and density at these levels occur near the pole. Densities are highest in summer when the circulation pattern is dominated by an anticyclone centered over the pole. Lowest values occur in winter and are associated with the polar cyclone that is normally centered off the east coast of northern Greenland.

Meteorological rocket network observations indicate that in tropical areas variability of seasonal means is less than day-to-day variability. In summer, observed day-to-day variations for all latitudes have rms values of 2 to 4 percent for density and 3 to 4°C for temperature at 50 km (typical of the 30- to 60-km layer). These are only slightly greater than random instrumentation errors in meteorological rocket measurements. Near the North Pole in winter the 50-km rms variations of density are nearly 16 percent and the rms variations of temperature are 13 to 14°C. The winter observations at mid and high latitudes show bimodal or rectangular distributions.

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